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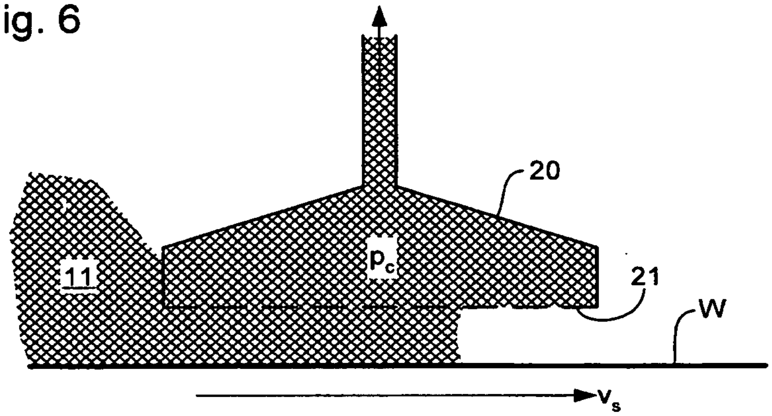
(54) Lithographic apparatus and device manufacturing method

(57) A porous member is used in a liquid removal system of an immersion lithographic projection apparatus to smooth uneven flows. A pressure differential across the porous member may be maintained at below the bubble point of the porous member so that a single-phase liquid flow is obtained. Alternatively, the porous member may be used to reduce unevenness in a two-phase flow.

Fig. 6



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Description

[0001] The present invention relates to a lithographic apparatus and a method for manufacturing a device.

[0002] A lithographic apparatus is a machine that applies a desired pattern onto a substrate, usually onto a target portion of the substrate. A lithographic apparatus can be used, for example, in the manufacture of integrated circuits (ICs). In that instance, a patterning device, which is alternatively referred to as a mask or a reticle, may be used to generate a circuit pattern to be formed on an individual layer of the IC. This pattern can be transferred onto a target portion (e.g. comprising part of, one, or several dies) on a substrate (e.g. a silicon wafer). Transfer of the pattern is typically via imaging onto a layer of radiation-sensitive material (resist) provided on the substrate. In general, a single substrate will contain a network of adjacent target portions that are successively patterned. Known lithographic apparatus include so-called steppers, in which each target portion is irradiated by exposing an entire pattern onto the target portion at one time, and so-called scanners, in which each target portion is irradiated by scanning the pattern through a radiation beam in a given direction (the "scanning"-direction) while synchronously scanning the substrate parallel or anti-parallel to this direction. It is also possible to transfer the pattern from the patterning device to the substrate by imprinting the pattern onto the substrate.

[0003] It has been proposed to immerse the substrate in the lithographic projection apparatus in a liquid having a relatively high refractive index, e.g. water, so as to fill a space between the final element of the projection system and the substrate. The point of this is to enable imaging of smaller features since the exposure radiation will have a shorter wavelength in the liquid. (The effect of the liquid may also be regarded as increasing the effective numerical aperture (NA) of the system and also increasing the depth of focus.) Other immersion liquids have been proposed, including water with solid particles (e.g. quartz) suspended therein.

[0004] However, submersing the substrate or substrate and substrate table in a bath of liquid (see for example United States patent US 4,509,852, hereby incorporated in its entirety by reference) means that there is a large body of liquid that must be accelerated during a scanning exposure. This requires additional or more powerful motors and turbulence in the liquid may lead to undesirable and unpredictable effects.

[0005] One of the solutions proposed is for a liquid supply system to provide liquid on only a localized area of the substrate and in between the final element of the projection system and the substrate (the substrate generally has a larger surface area than the final element of the projection system). One way which has been proposed to arrange for this is disclosed in PCT patent application no. WO 99/49504, hereby incorporated in its entirety by reference. As illustrated in Figures 2 and 3, liquid is supplied by at least one inlet IN onto the substrate, preferably along the direction of movement of the substrate relative to the final element, and is removed by at least one outlet OUT after having passed under the projection system. That is, as the substrate is scanned beneath the element in a -X direction, liquid is supplied at the +X side of the element and taken up at the -X side. Figure 2 shows the arrangement schematically in which liquid is supplied via inlet IN and is taken up on the other side of the element by outlet OUT which is connected to a low pressure source. In the illustration of Figure 2 the liquid is supplied along the direction of movement of the substrate relative to the final element, though this does not need to be the case. Various orientations and numbers of in- and out-lets positioned around the final element are possible, one example is illustrated in Figure 3 in which four sets of an inlet with an outlet on either side are provided in a regular pattern around the final element.

[0006] In the immersion lithography arrangements described herein, removal of an immersion liquid typically involves a two-phase flow - the immersion liquid mixes with ambient gas (e.g., air) or gas from a gas seal used to confine the immersion liquid. Such a two-phase flow is not very stable, especially when large pressure differentials are used to create strong gas flows to confine the immersion liquid or to ensure that all liquid is collected, and the resulting vibration is undesirable. High pressure gas flows may also cause evaporative drying of liquid remaining on the substrate leading to thermal gradients. Gas flows spilling over into the path of interferometer beams may also affect the accuracy of substrate table position measurements because the interferometer is very sensitive to changes in the refractive index of the gas in the path of the interferometer beams, such as may be caused by changes in temperature, pressure and humidity.

[0007] Accordingly, it would be advantageous, for example, to provide an arrangement to remove liquid from the vicinity of the substrate effectively and without generating significant vibration or other disturbances.

[0008] According to an aspect of the invention, there is provided a lithographic projection apparatus arranged to project a pattern from a patterning device onto a substrate using a projection system and having a liquid supply system arranged to supply a liquid to a space between the projection system and the substrate, comprising a liquid removal system including:

a conduit having an open end adjacent a volume in which liquid may be present;
a porous member between the end of the conduit and the volume; and
a suction device arranged to create a pressure differential across the porous member.

[0009] According to an aspect of the invention, there is provided a device manufacturing method, comprising:

projecting a patterned beam of radiation through a

liquid onto a substrate using a projection system; and removing liquid from a volume by providing a pressure differential across a porous member bounding at least in part the volume.

[0010] Embodiments of the invention will now be described, by way of example only, with reference to the accompanying schematic drawings in which corresponding reference symbols indicate corresponding parts, and in which:

Figure 1 depicts a lithographic apparatus according to an embodiment of the invention;
Figures 2 and 3 depict a liquid supply system for use in a lithographic projection apparatus;
Figure 4 depicts another liquid supply system for use in a lithographic projection apparatus;
Figure 5 depicts another liquid supply system for use in a lithographic projection apparatus;
Figure 6 depicts a liquid removal device according to a particular embodiment of the invention;
Figure 7 is an enlarged view of part of Figure 6;
Figure 8 depicts a liquid supply and removal system according to a particular embodiment of the invention;
Figure 8a depicts a variant of the liquid supply and removal system of Figure 8;
Figure 9 depicts a variant of the liquid supply and removal system of Figure 8;
Figure 10 depicts another variant of the liquid supply and removal system of Figure 8;
Figure 11 depicts still another variant of the liquid supply and removal system of Figure 8;
Figure 12 depicts a liquid supply and removal system according to another particular embodiment of the invention;
Figure 13 depicts a variant of the liquid supply and removal system of Figure 12;
Figure 14 depicts a manifold in a liquid removal system according to another particular embodiment of the invention;
Figure 15 depicts a variant of the manifold of Figure 14
Figure 16 depicts a liquid flow regulation system usable in embodiments of the invention;
Figure 17 depicts a variant of the liquid flow regulation system of Figure 16;
Figures 18 and 19 depict hydrophobic and hydrophilic capillaries used to extract liquid and gas respectively; and
Figures 20a to 20d depict the use of hydrophilic and hydrophobic capillaries for separate extraction of liquid and gas from a channel.

[0011] Figure 1 schematically depicts a lithographic apparatus according to one embodiment of the invention. The apparatus comprises:

- an illumination system (illuminator) IL configured to condition a radiation beam PB (e.g. UV radiation or DUV radiation);
- a support structure (e.g. a mask table) MT constructed to support a patterning device (e.g. a mask) MA and connected to a first positioner PM configured to accurately position the patterning device in accordance with certain parameters;
- a substrate table (e.g. a wafer table) WT constructed to hold a substrate (e.g. a resist-coated wafer) W and connected to a second positioner PW configured to accurately position the substrate in accordance with certain parameters; and
- a projection system (e.g. a refractive projection lens system) PL configured to project a pattern imparted to the radiation beam PB by patterning device MA onto a target portion C (e.g. comprising one or more dies) of the substrate W.

[0012] The illumination system may include various types of optical components, such as refractive, reflective, magnetic, electromagnetic, electrostatic or other types of optical components, or any combination thereof, for directing, shaping, or controlling radiation.

[0013] The support structure supports, i.e. bears the weight of, the patterning device. It holds the patterning device in a manner that depends on the orientation of the patterning device, the design of the lithographic apparatus, and other conditions, such as for example whether or not the patterning device is held in a vacuum environment. The support structure can use mechanical, vacuum, electrostatic or other clamping techniques to hold the patterning device. The support structure may be a frame or a table, for example, which may be fixed or movable as required. The support structure may ensure that the patterning device is at a desired position, for example with respect to the projection system. Any use of the terms "reticle" or "mask" herein may be considered synonymous with the more general term "patterning device."

[0014] The term "patterning device" used herein should be broadly interpreted as referring to any device that can be used to impart a radiation beam with a pattern in its cross-section such as to create a pattern in a target portion of the substrate. It should be noted that the pattern imparted to the radiation beam may not exactly correspond to the desired pattern in the target portion of the substrate, for example if the pattern includes phase-shifting features or so called assist features. Generally, the pattern imparted to the radiation beam will correspond to a particular functional layer in a device being created in the target portion, such as an integrated circuit.

[0015] The patterning device may be transmissive or reflective. Examples of patterning devices include masks, programmable mirror arrays, and programmable LCD panels. Masks are well known in lithography, and include mask types such as binary, alternating phase-shift, and attenuated phase-shift, as well as vari-

ous hybrid mask types. An example of a programmable mirror array employs a matrix arrangement of small mirrors, each of which can be individually tilted so as to reflect an incoming radiation beam in different directions. The tilted mirrors impart a pattern in a radiation beam which is reflected by the mirror matrix.

[0016] The term "projection system" used herein should be broadly interpreted as encompassing any type of projection system, including refractive, reflective, catadioptric, magnetic, electromagnetic and electrostatic optical systems, or any combination thereof, as appropriate for the exposure radiation being used, or for other factors such as the use of an immersion liquid or the use of a vacuum. Any use of the term "projection lens" herein may be considered as synonymous with the more general term "projection system".

[0017] As here depicted, the apparatus is of a transmissive type (e.g. employing a transmissive mask). Alternatively, the apparatus may be of a reflective type (e.g. employing a programmable mirror array of a type as referred to above, or employing a reflective mask).

[0018] The lithographic apparatus may be of a type having two (dual stage) or more substrate tables (and/or two or more mask tables). In such "multiple stage" machines the additional tables may be used in parallel, or preparatory steps may be carried out on one or more tables while one or more other tables are being used for exposure.

[0019] Referring to Figure 1, the illuminator IL receives a radiation beam from a radiation source SO. The source and the lithographic apparatus may be separate entities, for example when the source is an excimer laser. In such cases, the source is not considered to form part of the lithographic apparatus and the radiation beam is passed from the source SO to the illuminator IL with the aid of a beam delivery system BD comprising, for example, suitable directing mirrors and/or a beam expander. In other cases the source may be an integral part of the lithographic apparatus, for example when the source is a mercury lamp. The source SO and the illuminator IL, together with the beam delivery system BD if required, may be referred to as a radiation system.

[0020] The illuminator IL may comprise an adjuster AD for adjusting the angular intensity distribution of the radiation beam. Generally, at least the outer and/or inner radial extent (commonly referred to as σ-outer and σ-inner, respectively) of the intensity distribution in a pupil plane of the illuminator can be adjusted. In addition, the illuminator IL may comprise various other components, such as an integrator IN and a condenser CO. The illuminator may be used to condition the radiation beam, to have a desired uniformity and intensity distribution in its cross-section.

[0021] The radiation beam PB is incident on the patterning device (e.g., mask MA), which is held on the support structure (e.g., mask table MT), and is patterned by the patterning device. Having traversed the mask MA, the radiation beam PB passes through the projection system PL, which focuses the beam onto a target portion C of the substrate W. An immersion hood IH, which is described further below, supplies immersion liquid to a space between the final element of the projection system PL and the substrate W.

[0022] With the aid of the second positioner PW and position sensor IF (e.g. an interferometric device, linear encoder or capacitive sensor), the substrate table WT can be moved accurately, e.g. so as to position different target portions C in the path of the radiation beam PB. Similarly, the first positioner PM and another position sensor (which is not explicitly depicted in Figure 1) can be used to accurately position the mask MA with respect to the path of the radiation beam PB, e.g. after mechanical retrieval from a mask library, or during a scan. In general, movement of the mask table MT may be realized with the aid of a long-stroke module (coarse positioning) and a short-stroke module (fine positioning), which form part of the first positioner PM. Similarly, movement of the substrate table WT may be realized using a long-stroke module and a short-stroke module, which form part of the second positioner PW. In the case of a stepper (as opposed to a scanner) the mask table MT may be connected to a short-stroke actuator only, or may be fixed. Mask MA and substrate W may be aligned using mask alignment marks M1, M2 and substrate alignment marks P1, P2. Although the substrate alignment marks as illustrated occupy dedicated target portions, they may be located in spaces between target portions (these are known as scribe-lane alignment marks). Similarly, in situations in which more than one die is provided on the mask MA, the mask alignment marks may be located between the dies.

[0023] The depicted apparatus could be used in at least one of the following modes:

1. In step mode, the mask table MT and the substrate table WT are kept essentially stationary, while an entire pattern imparted to the radiation beam is projected onto a target portion C at one time (i.e. a single static exposure). The substrate table WT is then shifted in the X and/or Y direction so that a different target portion C can be exposed. In step mode, the maximum size of the exposure field limits the size of the target portion C imaged in a single static exposure.
2. In scan mode, the mask table MT and the substrate table WT are scanned synchronously while a pattern imparted to the radiation beam is projected onto a target portion C (i.e. a single dynamic exposure). The velocity and direction of the substrate table WT relative to the mask table MT may be determined by the (de-)magnification and image reversal characteristics of the projection system PL. In scan mode, the maximum size of the exposure field limits the width (in the non-scanning direction) of the target portion in a single dynamic exposure, whereas the length of the scanning motion determines the height

(in the scanning direction) of the target portion.

3. In another mode, the mask table MT is kept essentially stationary holding a programmable patterning device, and the substrate table WT is moved or scanned while a pattern imparted to the radiation beam is projected onto a target portion C. In this mode, generally a pulsed radiation source is employed and the programmable patterning device is updated as required after each movement of the substrate table WT or in between successive radiation pulses during a scan. This mode of operation can be readily applied to maskless lithography that utilizes programmable patterning device, such as a programmable mirror array of a type as referred to above.

[0024] Combinations and/or variations on the above described modes of use or entirely different modes of use may also be employed.

[0025] A further immersion lithography solution with a localized liquid supply system is shown in Figure 4. Liquid is supplied by two groove inlets IN on either side of the projection system PL and is removed by a plurality of discrete outlets OUT arranged radially outwardly of the inlets IN. The inlets IN and OUT can be arranged in a plate with a hole in its centre and through which the projection beam is projected. Liquid is supplied by one groove inlet IN on one side of the projection system PL and removed by a plurality of discrete outlets OUT on the other side of the projection system PL, causing a flow of a thin film of liquid between the projection system PL and the substrate W. The choice of which combination of inlet IN and outlets OUT to use can depend on the direction of movement of the substrate W (the other combination of inlet IN and outlets OUT being inactive).

[0026] Another immersion lithography solution with a localized liquid supply system solution which has been proposed is to provide the liquid supply system with a seal member which extends along at least a part of a boundary of the space between the final element of the projection system and the substrate table. Such a solution is illustrated in Figure 5. The seal member is substantially stationary relative to the projection system in the XY plane though there may be some relative movement in the Z direction (in the direction of the optical axis). A seal is formed between the seal member and the surface of the substrate.

[0027] Referring to Figure 5, reservoir 10 forms a contactless seal to the substrate around the image field of the projection system so that liquid is confined to fill a space between the substrate surface and the final element of the projection system. The reservoir is formed by a seal member 12 positioned below and surrounding the final element of the projection system PL. Liquid is brought into the space below the projection system and within the seal member 12. The seal member 12 extends a little above the final element of the projection system and the liquid level rises above the final element so that a buffer of liquid is provided. The seal member 12 has an inner periphery that at the upper end, in an embodiment, closely conforms to the shape of the projection system or the final element thereof and may, e.g., be round. At the bottom, the inner periphery closely conforms to the shape of the image field, e.g., rectangular though this need not be the case.

[0028] The liquid is confined in the reservoir by a gas seal 16 between the bottom of the seal member 12 and the surface of the substrate W. The gas seal is formed by gas, e.g. air or synthetic air but, in an embodiment, N_2 or another inert gas, provided under pressure via inlet 15 to the gap between seal member 12 and substrate and extracted via first outlet 14. The overpressure on the gas inlet 15, vacuum level on the first outlet 14 and geometry of the gap are arranged so that there is a high-velocity gas flow inwards that confines the liquid. Such a system is disclosed in United States patent application no. US 10/705,783, hereby incorporated in its entirety by reference.

[0029] Figures 6 and 7, the latter of which is an enlarged view of part of the former, illustrate a liquid removal device 20 according to an embodiment of the invention. The liquid removal device 20 comprises a chamber which is maintained at a slight underpressure p_c and is filled with the immersion liquid. The lower surface of the chamber is formed of a thin plate 21 having a large number of small holes, e.g. of diameter d_{hole} in the range of 5 to 50μm, and is maintained at a height h_{gap} in the range of 50 to 300μm above a surface from which liquid is to be removed, e.g. the surface of a substrate W. In an embodiment, perforated plate 21 is at least slightly hydrophilic, i.e. having a contact angle of less than 90° to the immersion liquid, e.g. water.

[0030] The underpressure p_c is such that the menisci 22 formed in the holes in the perforated plate 21 prevent gas being drawn into the chamber of the liquid removal device. However, when the plate 21 comes into contact with liquid on the surface W there is no meniscus to restrict flow and the liquid can flow freely into the chamber of the liquid removal device. Such a device can remove most of the liquid from the surface of a substrate W, though a thin film of liquid may remain, as shown in the drawings.

[0031] To improve or maximize liquid removal, the perforated plate 21 should be as thin as possible and the pressure differential between the pressure in the liquid p_{gap} and the pressure in the chamber p_c should be as high as possible, whilst the pressure differential between p_c and the pressure in the gas in the gap p_{air} must be low enough to prevent significant amounts of gas being drawn into the liquid removal device 20. It may not always be possible to prevent gas being drawn into the liquid removal device but the perforated plate will prevent large uneven flows that may cause vibration. Micro-sieves made by electroforming, photoetching and/or laser cutting can be used as the plate 21. Suitable sieves are made by Stork Veco B.V., of Eerbeek, the Netherlands.

Other porous plates or solid blocks of porous material may also be used, provided the pore size is suitable to maintain a meniscus with the pressure differential that will be experienced in use.

[0032] Figure 8 shows a liquid removal device incorporated in a seal member 12 of and immersion hood IH, according to a particular embodiment of the invention. Figure 8 is a cross-sectional view of one side of the seal member 12, which forms a ring (as used herein, a ring may be circular, rectangular or any other shape) at least partially around the exposure field of the projection system PL (not shown in Figure 8). In this embodiment, the liquid removal device 20 is formed by a ring-shaped chamber 31 near the innermost edge of the underside of the seal member 12. The lower surface of the chamber 31 is formed by a porous plate 30, as described above. Ring-shaped chamber 31 is connected to a suitable pump or pumps to remove liquid from the chamber and maintain the desired underpressure. In use, the chamber 31 is full of liquid but is shown empty here for clarity.

[0033] Outward of the ring-shaped chamber 31 are a gas extraction ring 32 and a gas supply ring 33. The gas supply ring 33 has a narrow slit in its lower part and is supplied with gas, e.g. air, artificial air or flushing gas, at a pressure such that the gas escaping out of the slit forms a gas knife 34. The gas forming the gas knife is extracted by suitable vacuum pumps connected to the gas extraction ring 32 so that the resulting gas flow drives any residual liquid inwardly where it can be removed by the liquid removal device and/or the vacuum pumps, which should be able to tolerate vapour of the immersion liquid and/or small liquid droplets. However, since the majority of the liquid is removed by the liquid removal device 20, the small amount of liquid removed via the vacuum system does not cause unstable flows which may lead to vibration.

[0034] While the chamber 31, gas extraction ring 32, gas supply ring 33 and other rings are described as rings herein, it is not necessary that they surround the exposure field or be complete. In an embodiment, such inlet (s) and outlet(s) may simply be circular, rectangular or other type of elements extending partially along one or more sides of the exposure field, such as for example, shown in Figures 2, 3 and 4.

[0035] In the apparatus shown in Figure 8, most of the gas that forms the gas knife is extracted via gas extraction ring 32, but some gas may flow into the environment around the immersion hood and potentially disturb the interferometric position measuring system IF. This can be prevented by the provision of an additional gas extraction ring 35 outside the gas knife, as shown in Figure 8A. Because in this embodiment, the liquid removal system can remove most, if not all, of the immersion liquid while at a height of 50 to 300μm above the surface of the substrate W or the substrate table WT, less onerous requirements are put on the seal member vertical position than when a gas bearing is used to confine the immersion liquid. This means that the seal member may be positioned vertically with a simpler actuation and control system. It also means that the requirements on the flatness of the substrate table and substrate are reduced, making it easier to construct devices such as sensors which need to be provided in the upper surface of the substrate table WT.

[0036] Removal of most of the liquid without evaporation also means that temperature gradients may be reduced, avoiding thermal deformation of the substrate, which can lead to printing errors. Evaporation may also be further minimized by using humid gas in the gas knife, e.g. with a relative humidity of about 50 to 75%, in combination with a pressure drop of about 100 to 500mbar and a flow rate of about 20 to 200 l/min.

[0037] Variants of this embodiment of the invention are shown in Figures 9 to 11. These variants are the same as that described above except in relation to the shape of the porous plate 30.

[0038] As shown in Figure 9, the porous plate 30a can be set at a slight angle, so that it is higher at the outside. The increasing gap between the porous plate 30a and substrate W or substrate table WT with distance from the centre of the exposure field, changes the shape of the meniscus 11a and helps to ensure that the area that is immersed in liquid has a more or less constant width.

[0039] In the variants shown in Figures 10 and 11, sharp corners 35 are used to limit the position of the meniscus 11a which is held by surface tension at the sharp corner. The sharp corner can be an obtuse angle, as shown in Figure 10, or a right angle, as shown in Figure 11. The shape of the gas extraction ring 32 can be adjusted as necessary.

[0040] A seal member according to another particular embodiment of the invention is shown in Figure 12, which is a similar view to Figure 8.

[0041] In the embodiment of Figure 12, a liquid bearing 36 is used to at least partially support the seal member 12, in place of separate actuators. The liquid, or hydro-dynamic, bearing 36 is formed by immersion liquid supplied under pressure to liquid supply chamber 37, in a known manner. The liquid is removed via two-phase extraction chamber 38, which is connected to suitable pumps (not shown) capable of handling the two-phase flow. A gas knife 34 confines the immersion liquid in the same manner as in previous embodiments.

[0042] The use of a liquid bearing 36 enables the seal member 12 to be maintained at a height of about 50 to 200μm above the substrate W or substrate table WT, easing control and flatness requirements as described above. At the same time, the two-phase extraction reduces the number of chambers that need to be formed in the seal member 12 and the number of hoses that need to be provided to it.

[0043] A porous plate 30 is provided across the bottom of two-phase extraction chamber 38, to control the flow of gas and liquid into it. By suitable selection of the size, number and arrangement of the pores in this plate, the two-phase flow is made steady, avoiding uneven flow

that may cause vibrations. As in the embodiments described above, a micro-sieve may be used as the plate 30.

[0044] Also as described in relation to the embodiment above, an inclination or a sharp edge may be provided in the porous plate 30 to control the position of the meniscus of the immersion liquid 11. Again, the removal of any residual liquid can be effected by a high-humidity, large flow gas knife 34 and the pressure of the gas knife can also be used to control the meniscus position.

[0045] In this, and other, embodiments of the invention, the shape of the part of the seal member that is in the immersion liquid may be adjusted to provide a desired degree of damping of vertical movements of the seal member 12. In particular, the width L_{da}, and hence area, of a part of the seal member which confines the liquid 11 into a narrow passage can be selected to provide the desired damping. The amount of damping will be determined by the area of the damping region, its height h_{da} above the substrate W or substrate table WT, the density ρ of the immersion liquid and its viscosity η. Damping may reduce variations in the position of the seal member due to vibrations, e.g. caused by uneven fluid flows.

[0046] A porous plate 41 may also be used to control the flow in an overflow drain 40, as shown in Figure 13. The overflow drain of Figure 13 may be applied in any of the embodiments of the invention described herein. The overflow drain is provided in an upper surface of the seal member 12 at a relatively large radius from the centre of the seal member 12. In case the space between the final element of the projection system PL and the substrate W becomes overfull of immersion liquid, the excess liquid will flow onto the top of the seal member 12 and into the drain 40. The drain 40 is normally full of liquid and maintained at a slight underpressure. The porous plate 41 prevents gas being drawn into the overflow drain but allows liquid to be drained away when required. The porous plate may also be set at a slight angle to the horizontal.

[0047] A porous separator can also be used in a manifold 50 that is provided in a liquid drain system that takes a two-phase flow from the immersion hood IH. As shown in Figure 14, the two-phase flow 51 is discharged into a manifold chamber 51 in which the liquid and gas separate. The gas is removed from the top of the manifold by a gas outlet 52 which is kept at a pressure of about -0.1barg by a suitable vacuum pump and pressure controller. A liquid removal pipe 53 extends to near the bottom of the manifold and is closed by a porous plate 54. The liquid removal pipe 53 is kept at a pressure below the bubble point of the porous plate 54, e.g. about -0.5barg, With this arrangement, even if the liquid level in the manifold drops below the bottom of the pipe 53, no gas will be drawn in to it, preventing any unwanted fluctuation in the pressure of the manifold 50, which might be communicated back to the immersion hood IH and cause a disturbance.

[0048] A variation of the manifold is shown in Figure 15. In this variant, which is the same as that of Figure 14 save as described below, the manifold is thermally isolated from its surroundings. The vacuum flow through the manifold will cause evaporation of the immersion liquid, leading to cooling. If the manifold is positioned close to or in thermal contact with a temperature sensitive part of the lithographic apparatus such as the reference or metrology frame, such cooling may have undesirable effects.

[0049] The manifold is therefore formed as a double-walled tank, comprising inner tank 50a and outer tank 50b, with a flow of temperature controlled liquid, e.g. water, between the walls of the inner and outer tanks. The temperature-controlled liquid is supplied at inlet 55 and removed at outlet 56. A series of baffles 57 are arranged in the space between the walls of the two tanks to ensure there are no regions of stagnant liquid. To avoid bridging the thermal isolation afforded by the double walled tank, no baffle contacts both inner and outer tanks. The rate of flow of temperature controlled liquid is determined to ensure that the temperature deviation of the outer tank 50b is within the limits imposed by any nearby temperature-sensitive components. An air gap or additional thermal insulation is preferably also provided between the outer tank and any nearby temperature-sensitive components.

[0050] A liquid supply system 60 that may be used in embodiments of the invention is shown in Figure 16. It comprises, in series: a source 61 of immersion liquid, e.g. a fab supply of ultra pure liquid; a constant flow restrictor 62; a variable flow restrictor 63; and a pressure regulator 64 with an external tap, a variable restriction 65 and a constant restriction 66, positioned just before the immersion hood IH. The pilot line for the pressure regulator 64 is connected downstream of the variable restriction 65 and so the input to the constant restriction 66 is at a constant pressure, hence the flow into the immersion hood is at constant pressure and rate.

[0051] An alternative liquid supply system 60' is shown in Figure 17. This is the same as the system 60 except as described below. In place of the regulator 64, and fixed restriction 66, a forward pressure regulator 67 and backward pressure regulator 68 are provided. Two pressure meters 69a, 69b are also provided. The forward pressure regulator 67 maintains the pressure downstream of it at a predetermined level and the backward pressure regulator maintains the pressure upstream of it at a predetermined level, in both cases independently of flow rate. Thus the variable flow restriction operates with constant upstream and downstream pressures, avoiding instability. The flow rate can be adjusted by adjustment of the pressure levels set by the pressure regulators 67, 68 and the variable flow restrictor 65, aided by the pressure sensors 69a, 69b which may also be used for monitoring purposes.

[0052] In a lithographic apparatus, a substrate is held on a substrate holder (often referred to as a pimple plate, burl plate or chuck), which comprises a flat plate of the same diameter as the substrate having a large number

of small pimples or burls on its major surfaces. The substrate holder is placed in a recess in the substrate table (mirror block) and the substrate placed on top of the substrate holder. A vacuum is developed in the spaces between the substrate table and holder and between the holder and substrate so that the substrate and holder are clamped in place by atmospheric pressure above the substrate. The recess in the substrate table is necessarily slightly larger than the substrate holder and substrate to accommodate variations in substrate size and placement. There is therefore a narrow groove or trench around the edge of the substrate in which immersion liquid may collect. While there the liquid causes no harm but it may be blown out of the groove by a gas bearing or gas knife in the immersion hood. Droplets on the substrate or substrate table that result may cause bubbles when the liquid meniscus under the immersion hood meets them.

[0053] The substrate holder is generally made of a material having a low thermal coefficient of expansivity, such as Zerodur or ULE. Some such materials are porous and in that case the surface pores are filled in to prevent contaminants becoming trapped there. However, it is proposed to leave the surface pores unfilled around the edge of the substrate holder and/or in a peripheral region. Then, when the substrate holder is used in an immersion lithography apparatus, the immersion liquid entering the groove will enter the pores of the substrate holder and not be blown out by the gas bearing or gas knife. If the substrate holder has an open-celled structure, the immersion liquid that has entered its pores can be removed by the vacuum system that clamps the substrate and holder to the table.

[0054] As shown in Figure 18, an extraction channel 70 connected to a volume from which only liquid is to be extracted via a narrow capillary 71 with hydrophilic walls 72 can be arranged so that liquid, e.g. water, is extracted by suitable underpressure -p, but when no liquid is present in the volume, a meniscus 73 prevents entry of gas, e.g. air. Conversely, as shown in Figure 19, an extraction channel 80 connected to the volume via a capillary 81 with hydrophobic walls 82 extracts gas, e.g. air, but when liquid, e.g. water, is present meniscus 83 prevents further flow. The exact level of underpressure -p required for these arrangements will depend on the liquid and gas involved, the size of the capillary and the contact angle of the liquid to the walls of the capillary. However, for a capillary of 0.05mm width an underpressure of 20mbar is suitable to enable selective extraction of water or air.

[0055] Extraction arrangements of this type can be used to remove selectively liquid or gas form any desired part of the lithographic apparatus. A particularly advantageous use is shown in Figures 20a to d, where liquid extraction channel 70 and gas extraction channel 80 are both connected to a trench in the substrate table WT around the edge of the substrate W. When the substrate edge is under the projection lens and hence the trench is filled with liquid, channel 70 extracts liquid so that there is a flow of liquid downwards. This draws any bubbles that might form in the trench, e.g. due to incomplete filling, downwards. This brings the bubbles to a position where the gas can be extracted via channel 80, but they will not enter the channel 70.. When the substrate edge is no longer under the projection lens the trench can quickly be emptied. In this way, escape of bubbles to interfere with imaging is prevented. By separating the liquid and gas flows, instabilities which may cause vibrations are avoided and the cooling effect of evaporation is minimized.

[0056] In European Patent Application No. 03257072.3, the idea of a twin or dual stage immersion lithography apparatus is disclosed. Such an apparatus is provided with two tables for supporting a substrate. Levelling measurements are carried out with a table at a first position, without immersion liquid, and exposure is carried out with a table at a second position, where immersion liquid is present. Alternatively, the apparatus has only one table.

[0057] Although specific reference may be made in this text to the use of lithographic apparatus in the manufacture of ICs, it should be understood that the lithographic apparatus described herein may have other applications, such as the manufacture of integrated optical systems, guidance and detection patterns for magnetic domain memories, flat-panel displays, liquid-crystal displays (LCDs), thin-film magnetic heads, etc. The skilled artisan will appreciate that, in the context of such alternative applications, any use of the terms "wafer" or "die" herein may be considered as synonymous with the more general terms "substrate" or "target portion", respectively. The substrate referred to herein may be processed, before or after exposure, in for example a track (a tool that typically applies a layer of resist to a substrate and develops the exposed resist), a metrology tool and/or an inspection tool. Where applicable, the disclosure herein may be applied to such and other substrate processing tools. Further, the substrate may be processed more than once, for example in order to create a multi-layer IC, so that the term substrate used herein may also refer to a substrate that already contains multiple processed layers.

[0058] The terms "radiation" and "beam" used herein encompass all types of electromagnetic radiation, including ultraviolet (UV) radiation (e.g. having a wavelength of or about 365, 248, 193, 157 or 126 nm).

[0059] The term "lens", where the context allows, may refer to any one or combination of various types of optical components, including refractive and reflective optical components.

[0060] While specific embodiments of the invention have been described above, it will be appreciated that the invention may be practiced otherwise than as described. For example, where applicable, the invention may take the form of a computer program containing one or more sequences of machine-readable instructions de-

scribing a method as disclosed above, or a data storage medium (e.g. semiconductor memory, magnetic or optical disk) having such a computer program stored therein.

[0061] The present invention can be applied to any immersion lithography apparatus, in particular, but not exclusively, those types mentioned above. The immersion liquid used in the apparatus may have different compositions, according to the desired properties and the wavelength of exposure radiation used. For an exposure wavelength of 193nm, ultra pure water or water-based compositions may be used and for this reason the immersion liquid is sometimes referred to as water and water-related terms such as hydrophilic, hydrophobic, humidity, etc. may be used. However, it is to be understood that embodiments of the present invention may be used with other types of liquid in which case such water-related terms should be considered replaced by equivalent terms relating to the immersion liquid used.

[0062] The descriptions above are intended to be illustrative, not limiting. Thus, it will be apparent to one skilled in the art that modifications may be made to the invention as described without departing from the scope of the claims set out below.

Claims

1. A lithographic projection apparatus arranged to project a pattern from a patterning device onto a substrate using a projection system and having a liquid supply system arranged to supply a liquid to a space between the projection system and the substrate, comprising a liquid removal system including:

   a conduit having an open end adjacent a volume in which liquid will be present;
   a porous member between the end of the conduit and the volume; and
   a suction device arranged to create a pressure differential across the porous member.

2. The apparatus according to claim 1, wherein the liquid removal system is arranged to remove liquid from a volume adjacent the space.

3. The apparatus according to claim 2, further comprising a member at least partially surrounding the space and wherein the conduit comprises a recess in a surface of the member facing the substrate, the porous member closing the recess.

4. The apparatus according to claim 3, wherein the member forms a closed loop around the space and the recess extends around the whole of the member.

5. The apparatus according to claim 3 or 4, wherein the member further comprises a gas supply circuit having an outlet in a surface facing the substrate so as to form a gas knife to remove residual liquid from a surface of the substrate, the gas knife being located radially outwardly of the recess.

6. The apparatus according to claim 5, wherein the member further comprises a gas extraction circuit having an inlet located between the recess and the gas knife.

7. The apparatus according to claim 5 or 6, wherein the member further comprises a gas extraction circuit having an inlet located radially outwardly of the gas knife.

8. The apparatus according to any one of claims 3 to 7, wherein the member further comprises a liquid supply circuit having an outlet in a surface facing the substrate so as to form a liquid bearing to at least partly support the weight of the member, the liquid bearing being located radially inwardly of the recess.

9. The apparatus according to any one of claims 3 to 8, wherein, during use, the member is supported at a height above the substrate in the range of from 50 to 300μm.

10. The apparatus according to any one of the preceding claims, further comprising a member at least partially surrounding the space and wherein the conduit comprises a recess in a surface of the member facing away from the substrate, the porous member closing the recess.

11. The apparatus according to any one of the preceding claims, wherein the liquid removal system comprises a liquid/gas separation manifold and the conduit comprises a pipe extending into a lower part of the manifold.

12. The apparatus according to any one of the preceding claims, wherein the porous member has pores having a diameter in the range of from 5 to 50μm.

13. The apparatus according to any one of the preceding claims, wherein the porous member is hydrophilic.

14. A device manufacturing method, comprising:

    projecting a patterned beam of radiation through a liquid onto a substrate using a projection system; and
    removing liquid from a volume by providing a pressure differential across a porous member bounding at least in part the volume.

15. The method according to claim 14, wherein the volume is adjacent a space comprising the liquid through which the patterned beam is projected.

16. The method according to claim 15, comprising removing the liquid from the volume using a recess in a surface, facing the substrate, of a member at least partially surrounding the space, the porous member closing the recess.

17. The method according to claim 16, wherein the member forms a closed loop around the space and the recess extends around the whole of the member.

18. The method according to claim 16 or 17, further comprising supplying gas from a surface facing the substrate so as to form a gas knife to remove residual liquid from a surface of the substrate, the gas being supplied at a position radially outwardly of the recess.

19. The method according to claim 18, further comprising removing gas from a position between the recess and the position where the gas is being supplied.

20. The method according to claim 18 or 19, further comprising removing gas from a position located radially outwardly of the position where the gas is being supplied.

21. The method according to any one of claims 16 to 20, further comprising supplying liquid from a surface facing the substrate so as to form a liquid bearing to at least partly support the weight of the member, the liquid being supplied at a position radially inwardly of the recess.

22. The method according to any one of claims 16 to 21, comprising supporting the member at a height above the substrate in the range of from 50 to 300μm.

23. The method according to any one of claims 14 to 22, comprising removing the liquid from the volume using a recess in a surface, facing away from the substrate, of a member at least partially surrounding the space, the porous member closing the recess.

24. The method according to any one of claims 14 to 23, comprising removing the liquid from the volume through a pipe extending into a lower part of a liquid/gas manifold comprising the volume.

Fig. 1

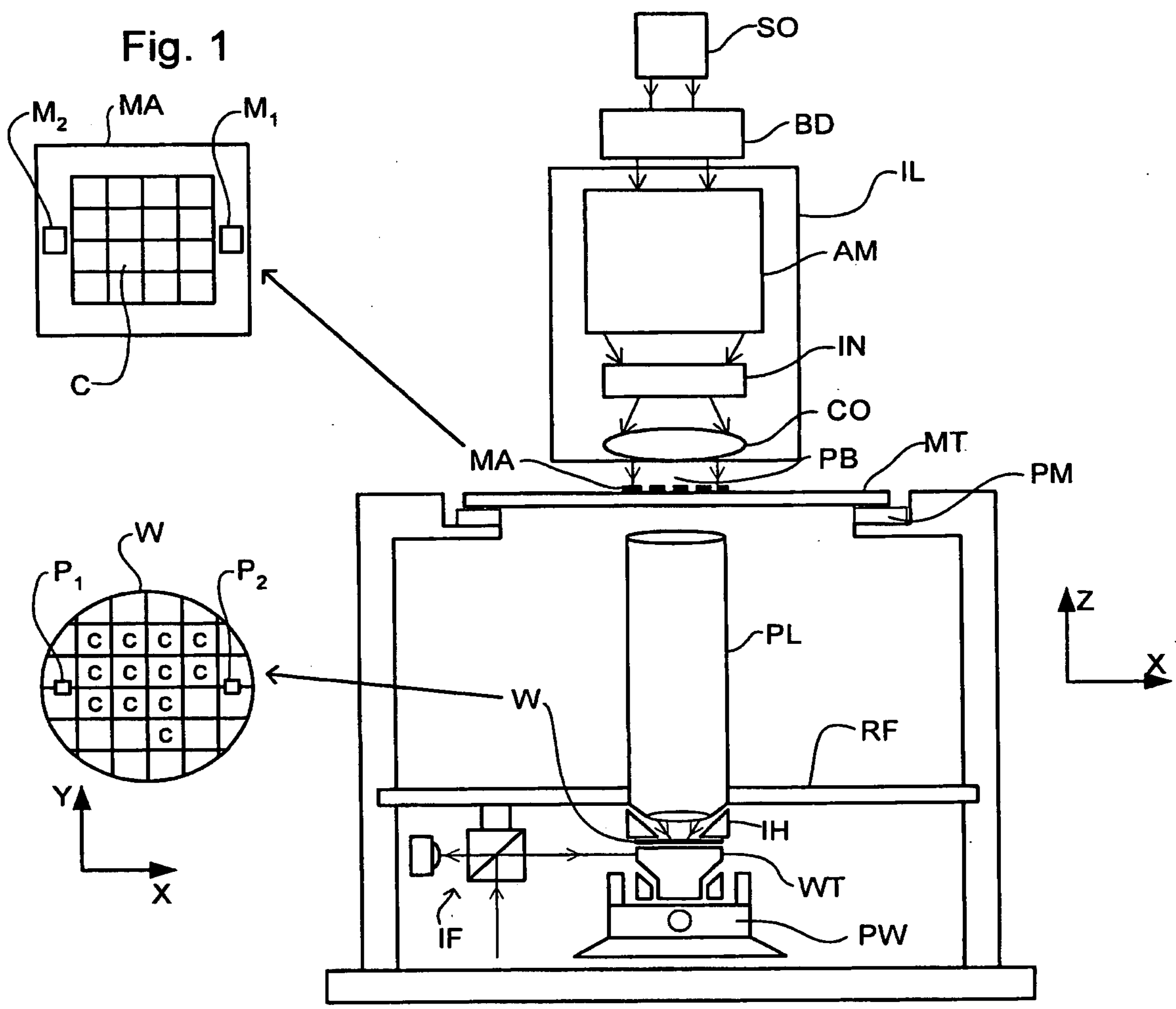
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Fig. 2

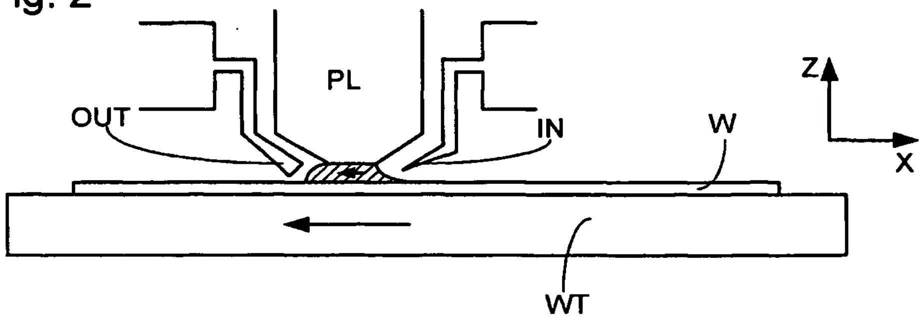


Fig. 3

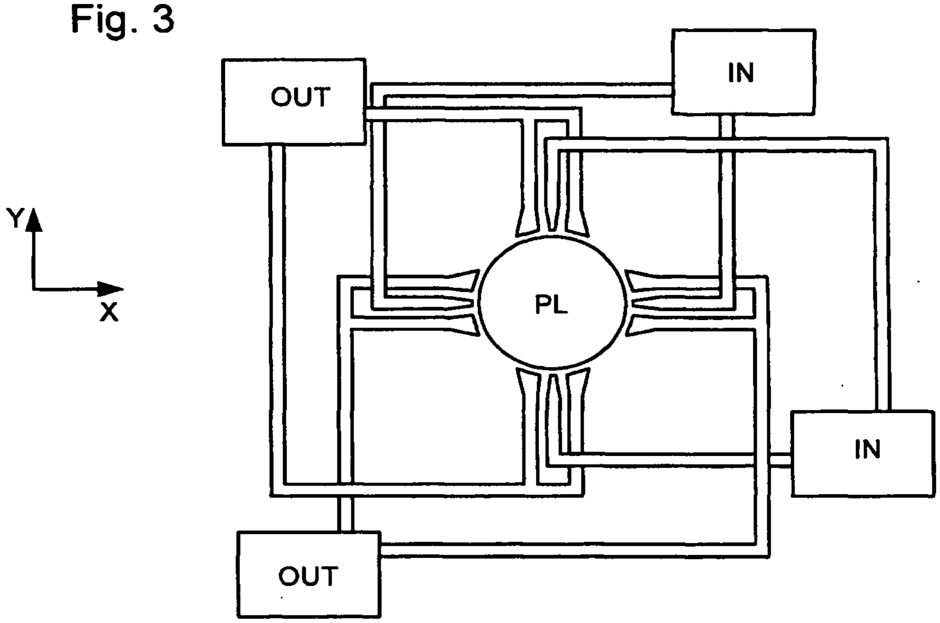


Fig. 4

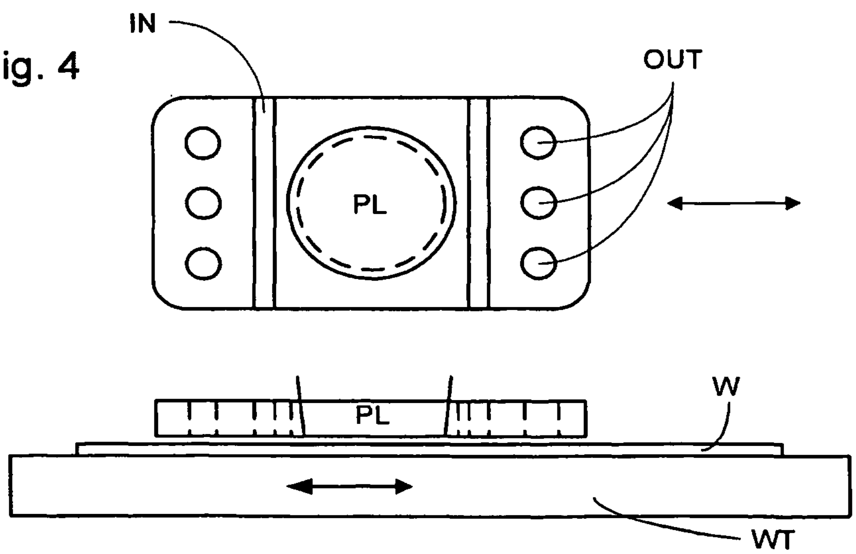


Fig. 5

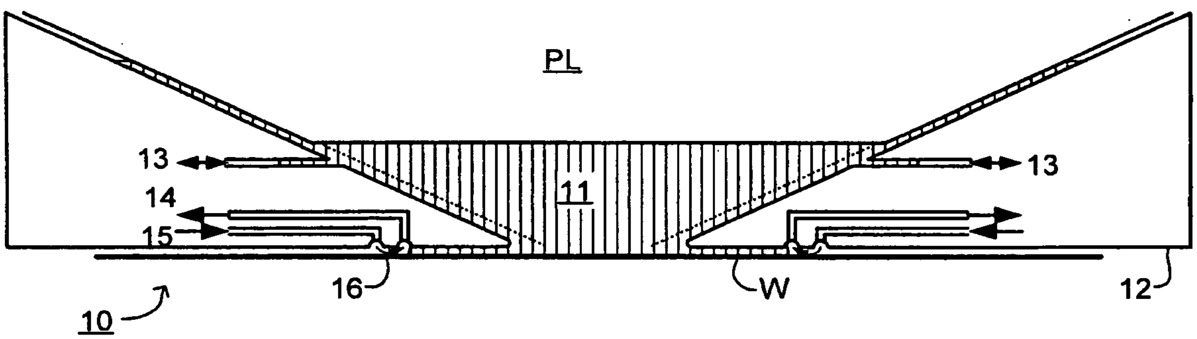


Fig. 6

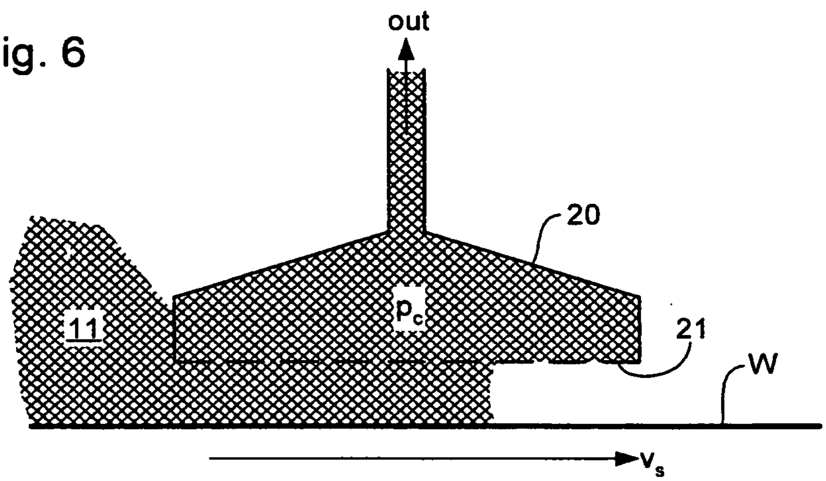


Fig. 7

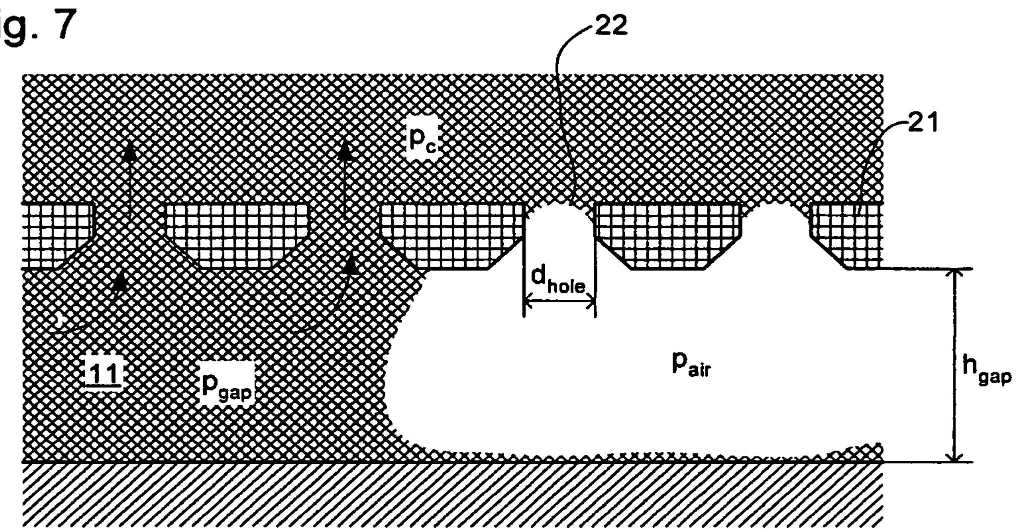


Fig. 8

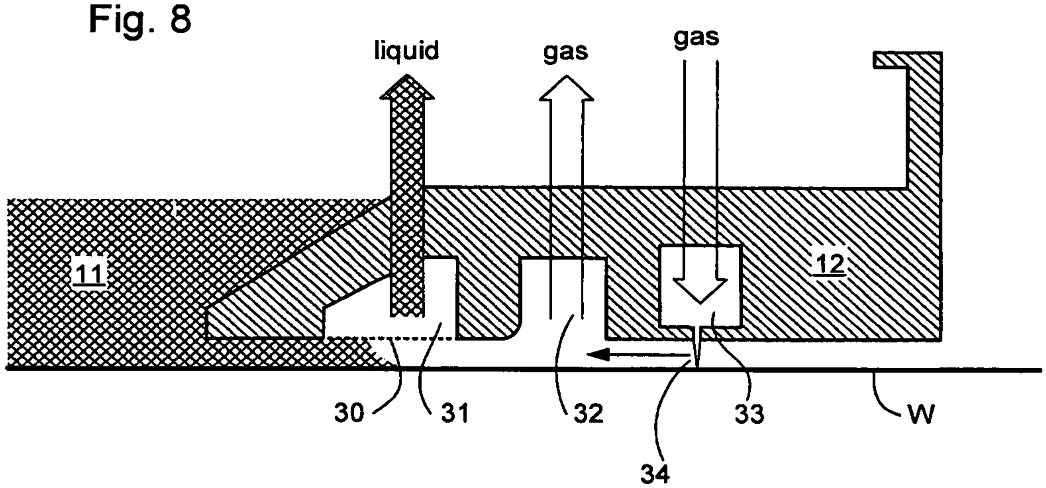


Fig. 8a

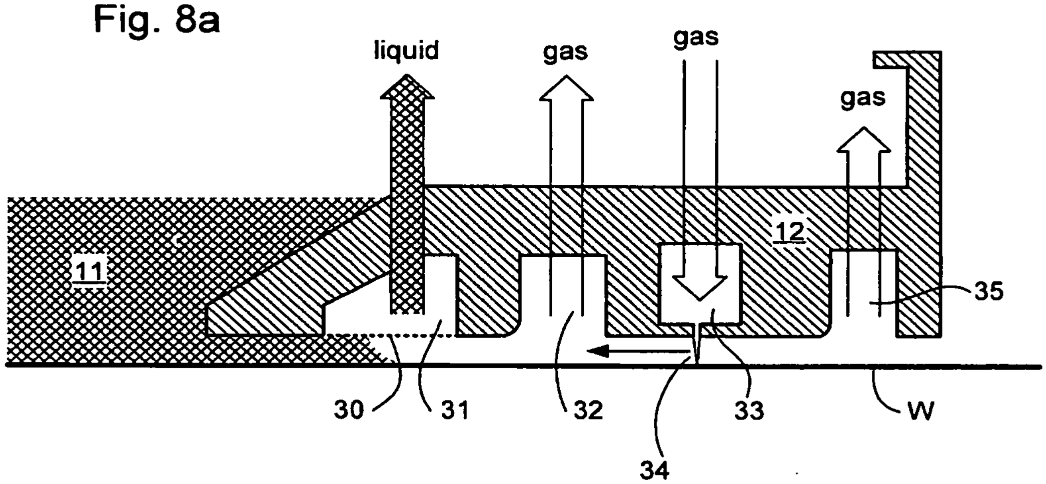


Fig. 9

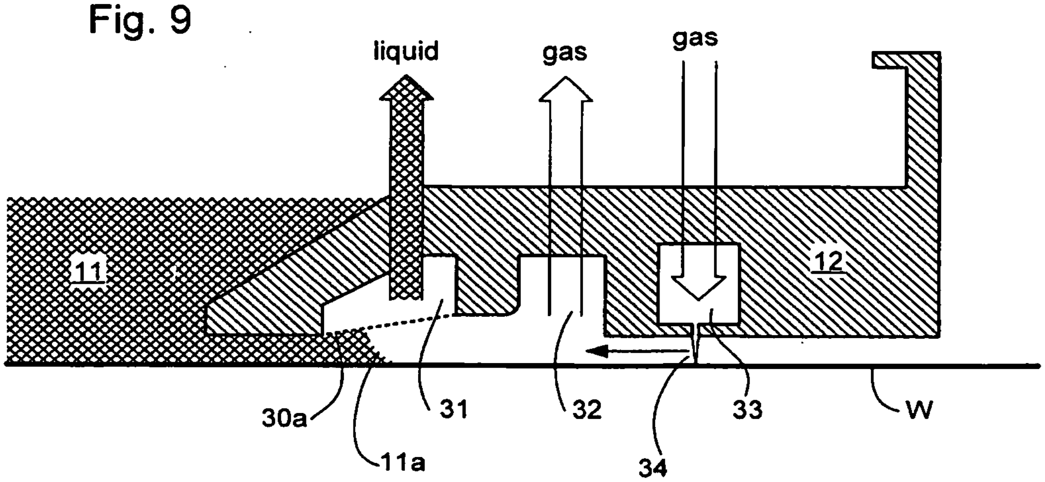


Fig. 10

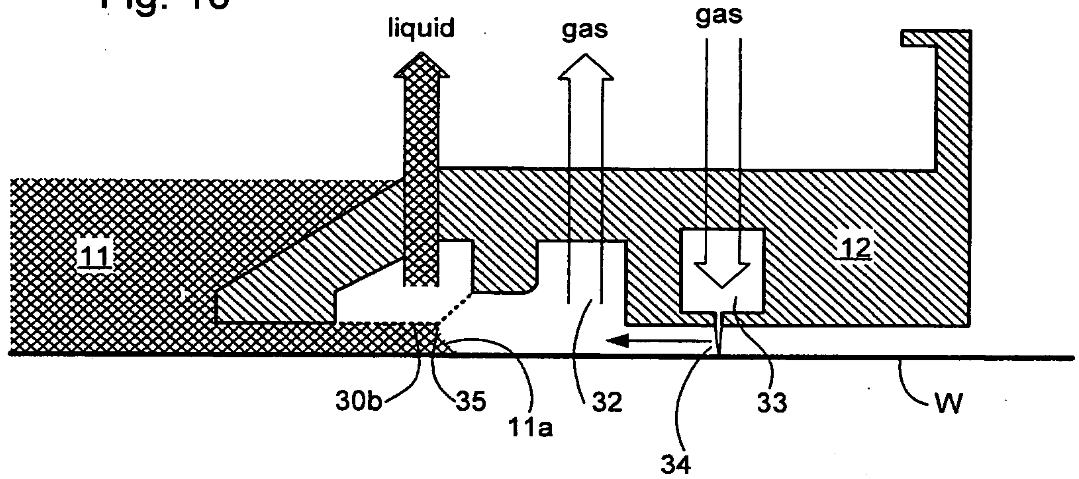


Fig. 11

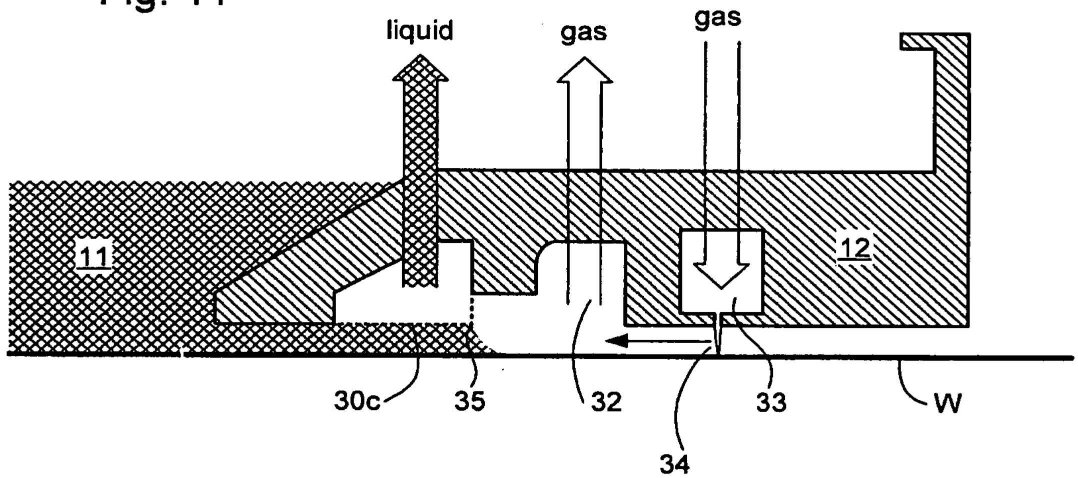


Fig. 12

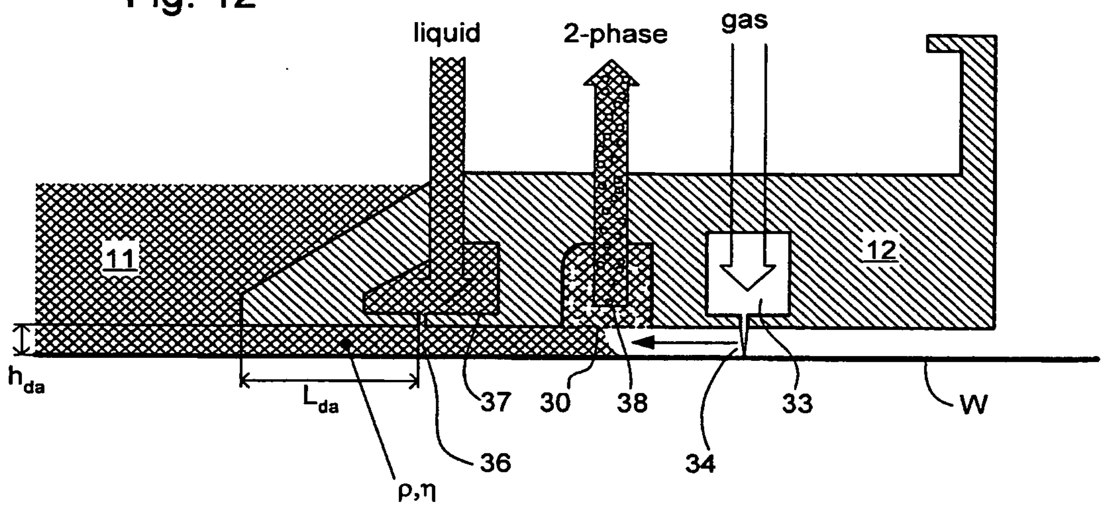


Fig. 13

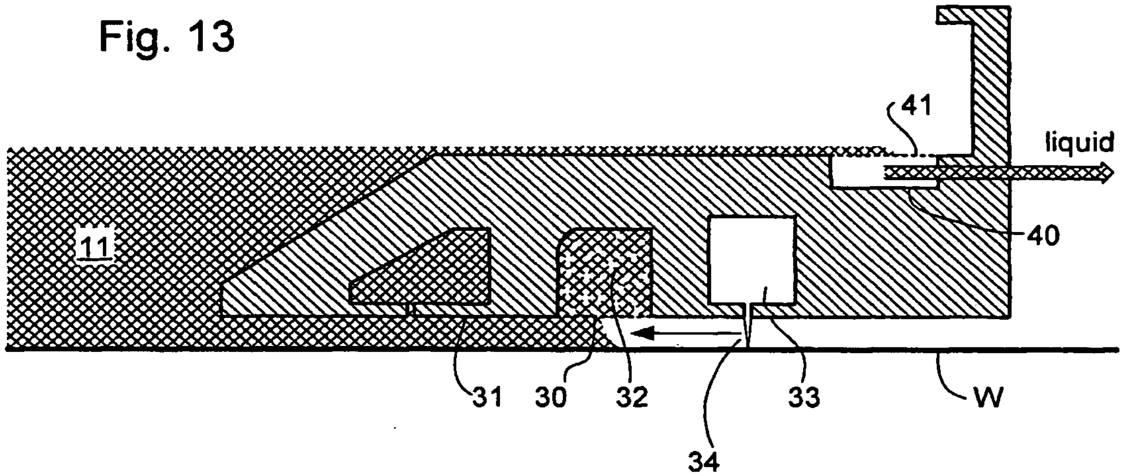


Fig. 14

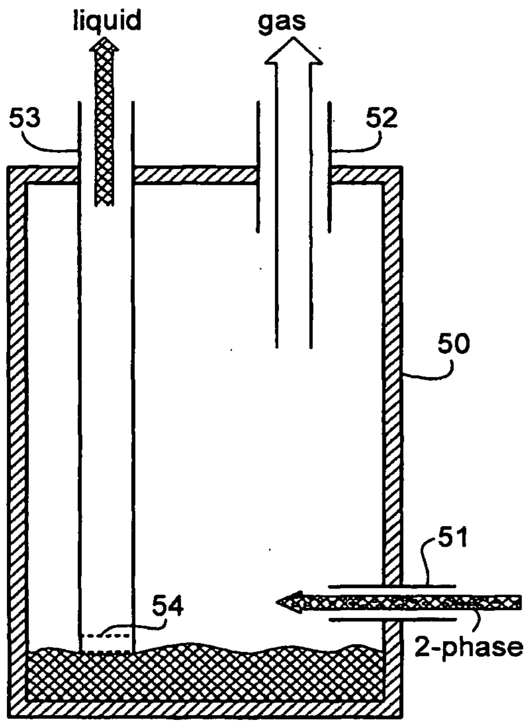


Fig. 15

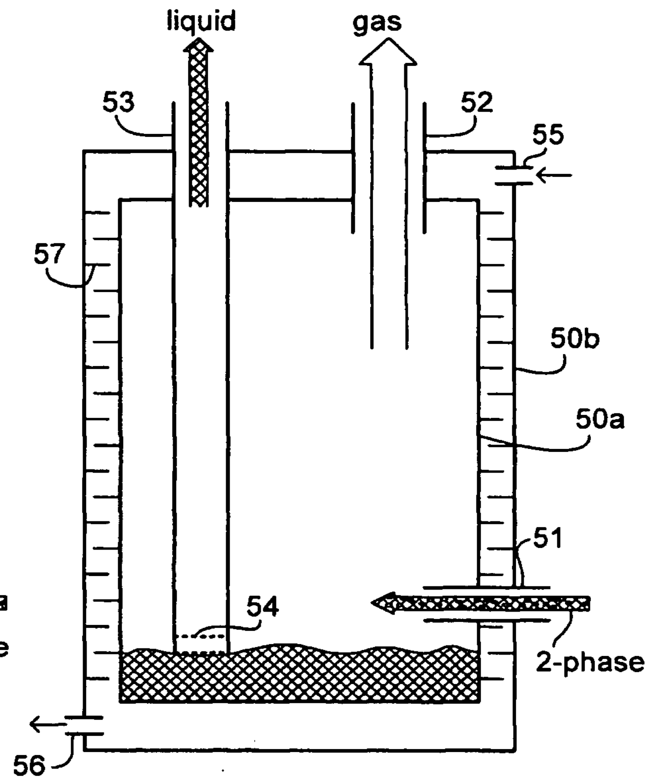


Fig. 16

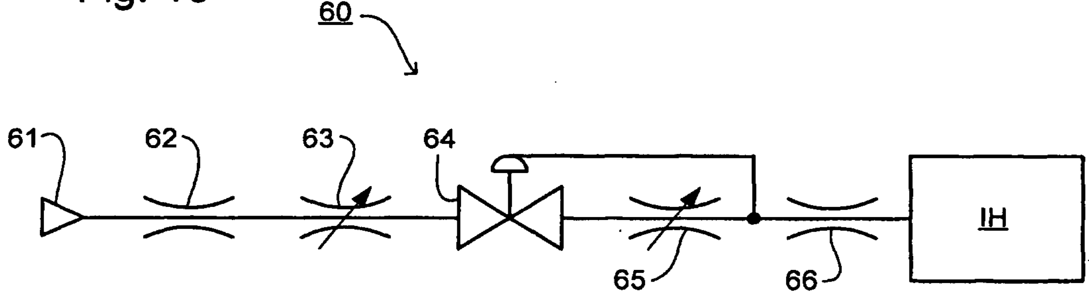


Fig. 17

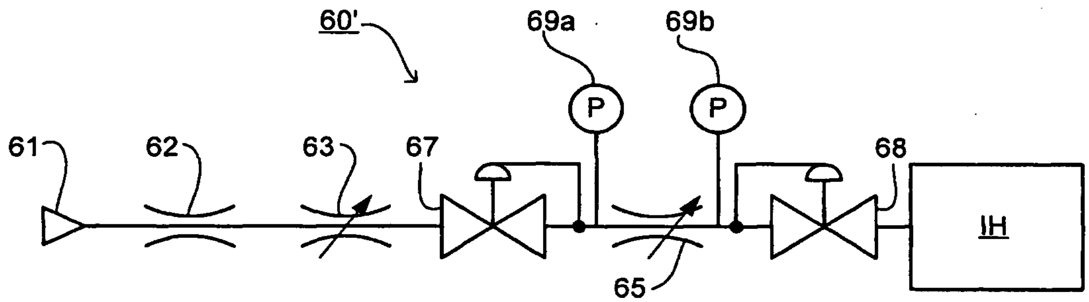


Fig. 18

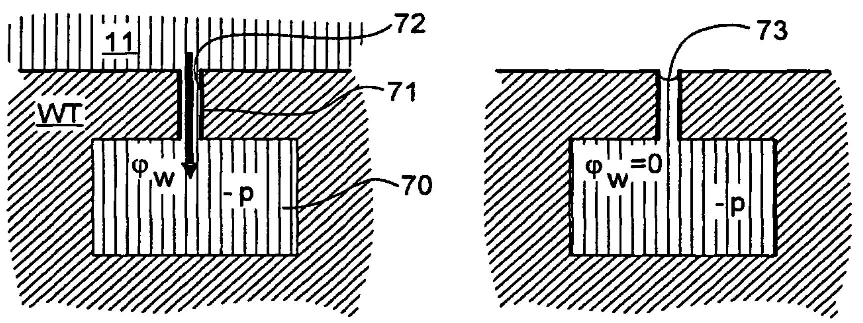


Fig. 19

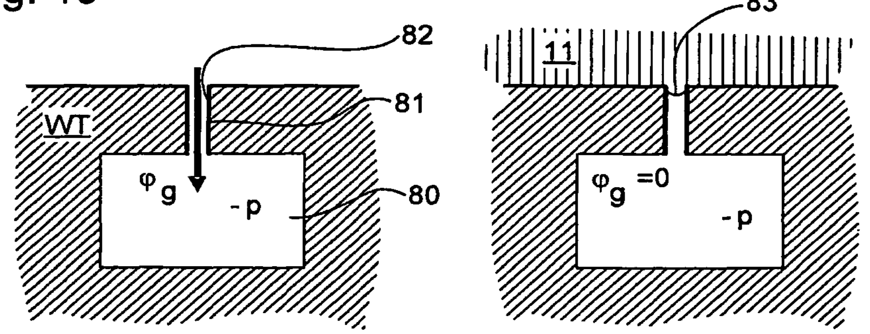


Fig. 20a

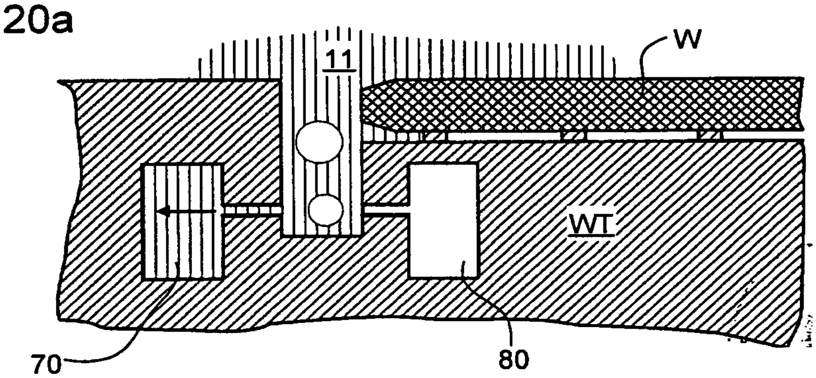


Fig. 20b

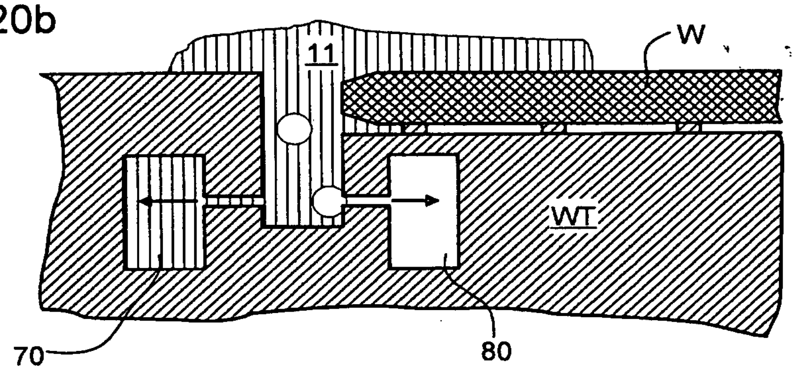


Fig. 20c

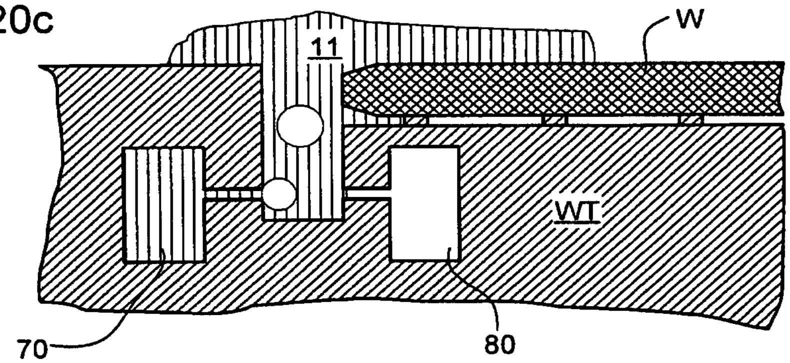
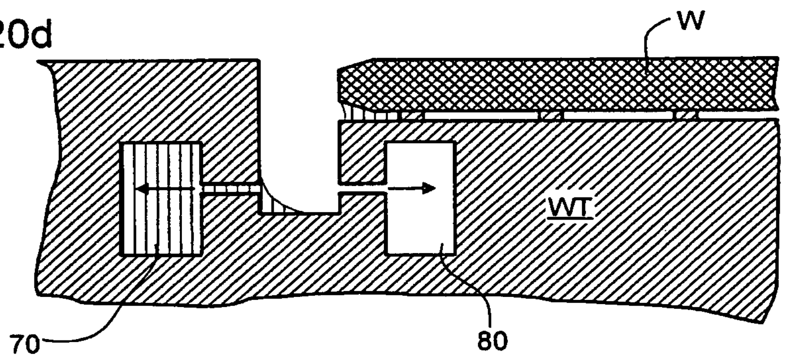


Fig. 20d



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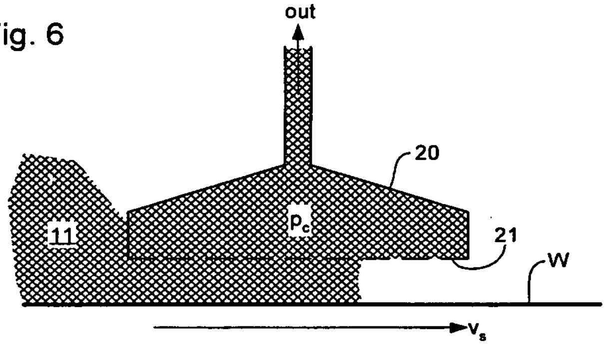
(54) **Lithographic apparatus and device manufacturing method**

(57) A porous member is used in a liquid removal system of an immersion lithographic projection apparatus to smooth uneven flows. A pressure differential across the porous member may be maintained at below the bubble point of the porous member so that a single-phase liquid flow is obtained. Alternatively, the porous member may be used to reduce unevenness in a two-phase flow.

Fig. 6



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EUROPEAN SEARCH REPORT

Application Number
EP 05 25 4920

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
P,X P,A	WO 2005/024517 A (NIKON RESEARCH CORPORATION OF AMERICA; POON, ALEX KA TIM; KHO, LEONARD) 17 March 2005 (2005-03-17) * abstract * * paragraph [0003] - paragraph [0006] * * paragraph [0024] - paragraph [0026]; figures 2-6 * -----	1-4,8, 12, 14-17,21 5-7, 9-11,13, 18-20, 22-24	G03F7/20
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			TECHNICAL FIELDS SEARCHED (IPC)
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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	19 January 2006	van Toledo, W

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3

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